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An airborne stereo multispectral scanner (ASMSS) for bathymetric survey and reconnaissance

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AN AIRBORNE STEREO MULTISPECTRAL SCANNER (ASMSS) FOR BATHYMETRIC SURVEY AND RECONNAISSANCE

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ABSTRACT

The Airborne Stereo Multispectral Scanner (ASMSS) mission and design scenario are described. The obstacles to successful development of the scanner system are detailed. Results of simulation trials to determine errors relevant to system design considerations are provided. Finally, a relatively simple competing design scenario is presented.

1. INTRODUCTION

The rapid surveying of water depths, elevations, and surface material cover in coastal areas remains a significant concern for the Navy and the Defense Mapping Agency (DMA). Currently, the problem is being addressed by the development of the Airborne Bathymetric Survey (ABS). The ABS is composed of a laser sounder and a multispectral scanner, which operates at Thematic Mapper wavelengths. The laser sounder provides control points in the MSS image so that, with adaptive filter techniques, bathymetry may be extracted from MSS imagery. However, the use of a laser imposes power and weight restrictions on the airborne platform, as well as significant repair and maintenance problems. REPRINTS - PRHY

Stereo pairs obtained from aircraft have long been used in photogrammetry to obtain both elevation and depth data[1-2]. Therefore, another approach being investigated involves the preliminary study and conceptual design of an Airborne Stereo Multispectral Scanner (ASMSS). Such a scanner would provide not only charting of water depths from imagery but would give topographic and trafficability information as well. A design scenario would involve a nadir-looking multispectral sensor and uni-band fore and aft linear arrays, in a convergent configuration, which would emulate continuous strip cameras. This scenario follows the design concepts of the MAPSAT sensor[3-5]. Implicit in the MAPSAT design was the ability to acquire and maintain epipolar geometry between the two stereo sensors. In this way, stereo correlation of the imagery would become a unidimensional problem. However, the shifting attitude of the satellite platform would have to be controlled and well defined so that deviations from the epipolar condition could be effectively nullifed either by on-board sytems or by calculation during the rectification process of the imagery.

Placing such a sensor design onto an aircraft flying at low altitude presents difficulties in stereo image correlation due to the greater overall attitude variation as well as larger differential rates of attitude change. That is, the optimum condition of epipolarity can not be easily achieved. This lack of epipolarity in the stereo pair imagery would result in costly processing and a loss in timeliness of the information due to the difficult, if not impossible, digital correlation process. In the situation where the sensor is used for reconnaissance of an amphibious objective area (AOA), timeliness can become crucial.

A possible solution is to use on-board sensors to track the aircraft attitude changes and record the roll, pitch, and yaw motions as accurately as possible. This information might then be used to reconstruct the epipolarity condition so that uni-dimensional correlation is once more possible.

2. SYSTEM SPECIFICATIONS

TABLE 1.

EARLY GUIDANCE SPECIFICATIONS

PARAMETER	SPECIFICATION
A/C type	TBD
Altitude	4000 ft
Speed	275 kts

Sensor Inclination	
Nadir	0 Deg
Stereo	26.6 Deg
Swath Coverage	1 naut. mi.
Pixel Size	
Nadir	4 ft x 4 ft
Stereo	4 ft x .5 ft
Array Elements	1520
Bit Precision	10 bits
IFOV	1 mrad
TFOV	74.5 Deg
Spectral Range	6 bands, TBD

Table 1 provides early guidance specifications for the proposed scanner system. However, for the altitude and swath coverage mentioned, the FOV becomes rather large. A smaller FOV would make possible a much more effective and economical scanner optical design with an appropriate tradeoff on coverage rate. Hence, alternative, more complete specifications were derived. These are shown in Table 2.

TABLE 2.

NOMINAL SCANNER REQUIREMENTS LISTING

PARAMETER	SPECIFICATION	INFLUENCE
A/C Parameters		
A/C Type	P-3	
Speed	130 m/sec	Coverage rate, image blur, detector integration time
Altitude		
Nominal	915 m	Suggested from primer simulation
Survival	9150 m	
Environmental Params.		
Temperature		
Operating	-5 C to 45 C	Opto-mechanics of optical system; detector performance
Non-operating	-40 C to 65 C	
Vibration/stabilized	Schuler-tuned, inertially stabilized platform	
Attitude measurement sensors	14 or 16 bit precision	Stereo correlation, epipolarity
Sensor Design (Nadir and Stereo Sensors)		
Scanner Type	Pushbroom	Reduction of mechanical vibration
MTF	0.8 at Nyquist frequency	Optical blur function

S/N	> 1000:1	Size of optics, detector performance
Crosstalk	10% max	Detector diffusion MTF
Optical Design		
Sensor Inclination		
Nadir	0 Deg	Base/Height ratio, from primer simulation
Stereo	26.6 Deg	
Swath size	1 km	Coverage rate, detector array, IFOV, TFOV
Spatial Resolution	.5 m	System resolution, IFOV, altitude
IFOV		
Nadir	.5 mrad	
Stereo	.49 mrad	
TFOV		Easier FOV to design
Nadir	57.3 Deg	
Stereo	52.1 Deg	
Coverage Rate	396 km*km/hr(max)	Cost effectiveness
Receiver Aperture	100 cm*cm	S/N, size of optics, cost
Number of array elements	2000	IFOV
Bit precision	10 bit	Dynamic range, data rates, and data storage
Spectral Range, Nadir		
Band 1	402-422	Compatibility with SeaWIFFS sensor, detector type
Band 2	433-453	
Band 3	480-500	
Band 4	510-530	
Band 5	550-575	
Band 6	655-675	
Band 7	745-785	
Band 8	843-887	
Spectral Range, Stereo		
Band 5	550-575	
Spectral shape	TBD	
Polarization	< 5%	Coatings used on optics

3. PRELIMINARY SIMULATION RESULTS AND ERROR FORMULAE

A preliminary simulation of the displacement effects of aircraft attitude deviations on ASMSS imagery as a function of platform altitude and sensor inclination angle was coded

and run. The simulation assumed constant velocity, level flight along the flight line over a level to gently rolling ground plane, and random attitude changes that would occasionally exceed 3 to 4 degrees. The simulation called error formulae to calculate the magnitude of the displacement error of one stereo sensor relative to the other due to shifts in each axis of aircraft motion. The resulting error values were ramified into epipolar, non-epipolar, and 'heighting' errors. Epipolar error is due to attitude changes that force motion perpendicular to the flight line such as roll and yaw maneuvers. Non-epipolar error is pitch error resolvable along the flight line, or x-axis. Heighting errors are due to pitch motion as well. This has been discussed earlier by Welch[6]. Table 3 provides the formulae.

When epipolar error occurs between the two stereo sensors, a two dimensional correlation problem results. When only non-epipolar error (and heighting error for the simulation results) occurs, the optimum unidimensional correlation process exists. However, the correlation process becomes a function of time. That is, because of pitch motion, the appropriate correlation point may occur sooner or later in time.

The data were treated statistically and the results are shown in Figs. 1-4. Figs. 1-2 show the non-epipolar error due to pitch changes during flight. Figs. 3-4 show epipolar error due to roll and yaw motions of the platform. Notice that the heighting error (Fig. 1) shows a reverse tendency when compared to the other error plots.

Figs. 5-8 show what the error would be if it would indeed be possible to correct the imagery for the motion of the aircraft to a precision of 12 bits. Obviously, if more bit precision were used, the errors would be very small, becoming sub-pixel size. These plots demonstrate that if suitable corrections could be made to sub-pixel magnitudes, then the epipolar condition is recovered.

A more refined simulation is being developed that will allow further studies of the effects of platform motion on the imagery obtained from the sensor.

TABLE 3.

ERROR FORMULAE

HEIGHTING ERROR:

DELTA Z = B*(K2-K1)/(2*K1*(K1+K2)), where B is the base, K2 is Tan(beta), K1 is Tan(alpha). Alpha is the sensor inclination angle, and beta is the sum of the sensor inclination angle and some random pitch value.

NON-EPIPOLAR ERROR X-AXIS ERROR:

DELTA X = B*(K2-K1)/(2*(K1+K2)), where B and K's are defined as in the above.

EPIPOLAR TYPE ERROR (perpendicular displacement from the flight, or x- axis).

DISPLACEMENT ERROR DUE TO ROLL:

DELTA Y = SQR(((H-DELTA Z)/COS(BETA))©2*((1/COS(OMEGA))-1)), where omega is the some random roll angle for the platform.

DISPLACEMENT ERROR DUE TO YAW:

DELTA W = 2*SIN(KAP/2)*SQR(((B/2)+DELTA X)©2+(DELTA Y)©2)), where KAP(PA) is some random yaw angle.

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4. ALTERNATIVE DESIGN SCENARIO

As mentioned previously, the proposed ASMSS design poses difficulties due to aircraft motion while imagery is being taken. On-board sensors presently available for attitude measurements are good to 10 bit precision. An increase to 12 bit precision is possible. However, 14 to 16 bit resolution requires a much larger investment of time and money. NASA's Earth Resources Laboratory presently utilizes an on-board sensor on a Lear jet which gathers digital corrective data for pitch motion that is used later for image rectification. The corrective data is input to a software package, named GEOREF (now in its

20th version), which attempts to subtract the effects of pitch motion from the imagery collected. The software was developed in conjunction with the Coastal Research Institute at LSU. However, the performance of this software is well below what was hoped for. The funding ran out on the software development two years ago.

As a competing design concept, a simple, compact videographic system has been considered. In effect, a videographic camera, which can be designed to provide multispectral operation, would be utilized in what would be a normal photogrammetric mode. The camera would possess a gateable (shuttered) planar array that would, at each exposure station, 'snap' imagery. Given the standard 50 to 55 percent overlap, stereo multispectral imagery would be provided. Moreover, due to the use of the planar array, the data would be digi ., and the spectral resolution and dynamic range are much improved over conventional film. Industry[7] has recently developed a relatively inexpensive and extremely compact candidate videographic system which possesses an effective 1134 X 962 array. The camera head weighs less than a pound and can provide up to 42 frames/sec. Utilizing a standard VCR tape, up to 14000 images can be stored on a single tape.

Table 4 presents a short list of preliminary design specifications for the videographic stereo multispectral system.

TABLE 4.

PRELIMINARY VIDEOGRAPHIC SYSTEM SPECIFICATIONS

PARAMETER	SPECIFICATION
A/C Type	See Table 2.
Environmental Parameters	See Table 2. with the omission of the attitude measurement sensors.
Sensor Design	See Table 2. with the scanner replaced by videographic type system.
Optical Design (variations from Table 2.)	
Sensor inclination	0 Deg
Scene Size	about 1 km*km
IFOV	1.1 mrads
TFOV	62.6 Deg

5. CONCLUSION

The ASMSS system conceptual design has undergone preliminary investigation. The findings to date indicate that, theoretically, on-board attitude sensor correction of the imagery collected by the proposed scanner system can be performed. Practically, however, it appears to be an expensive avenue (with attendant risks) to multispectral, stereo imagery for Navy bathymetric charting and reconnaissance. An alternative design scenario utilizes a videographic, multispectral camera system that would emulate normal photogrammetric missions. This approach relies on known correlation techniques and the recent development of a candidate videographi system by industry.

6. ACKNOWLEDGEMENTS

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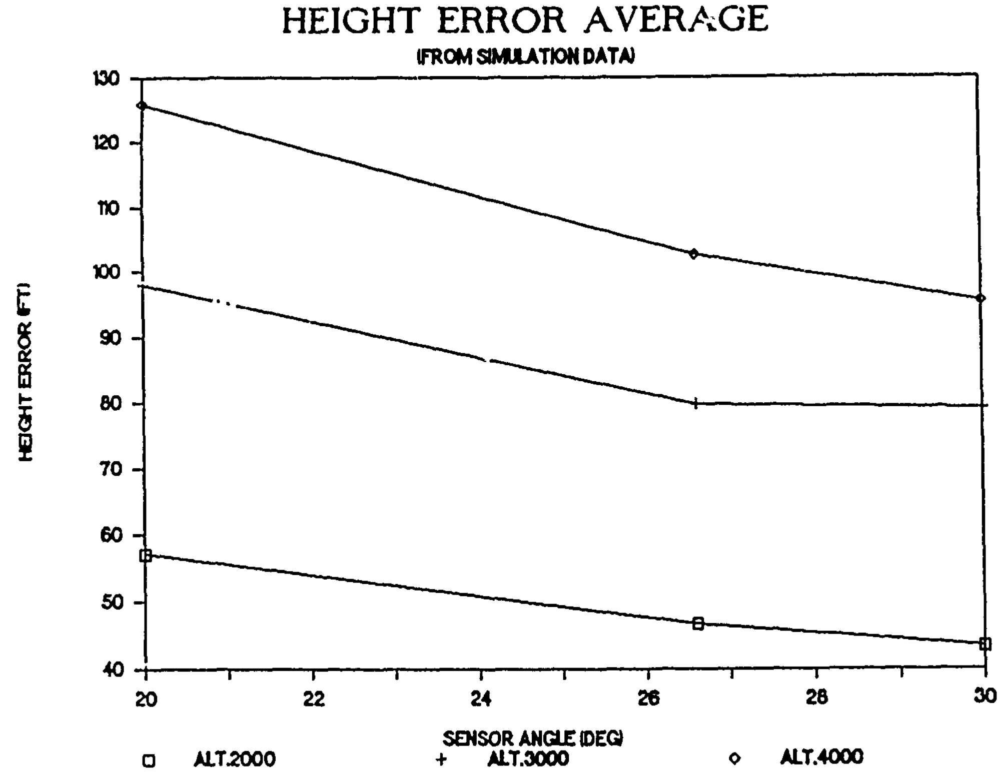

FIG 1.
Averaged height error data from simulation runs. The error is shown as a function of altitude and sensor inclination angle.

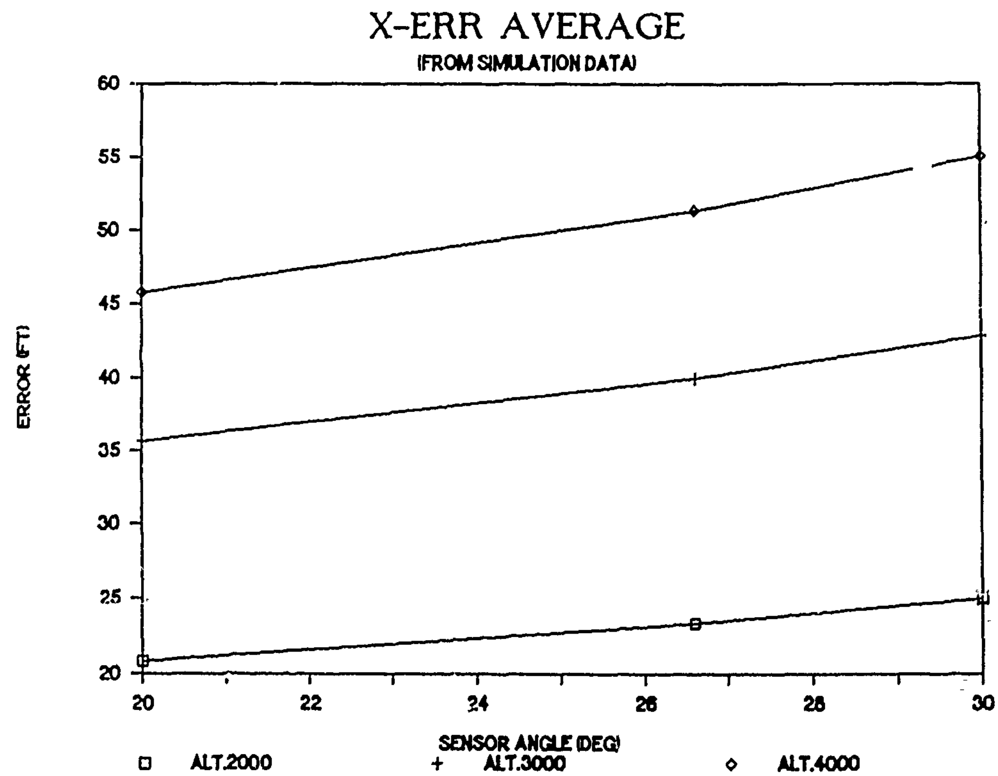

FIG 2.
Averaged x-axis error data from simulation runs.

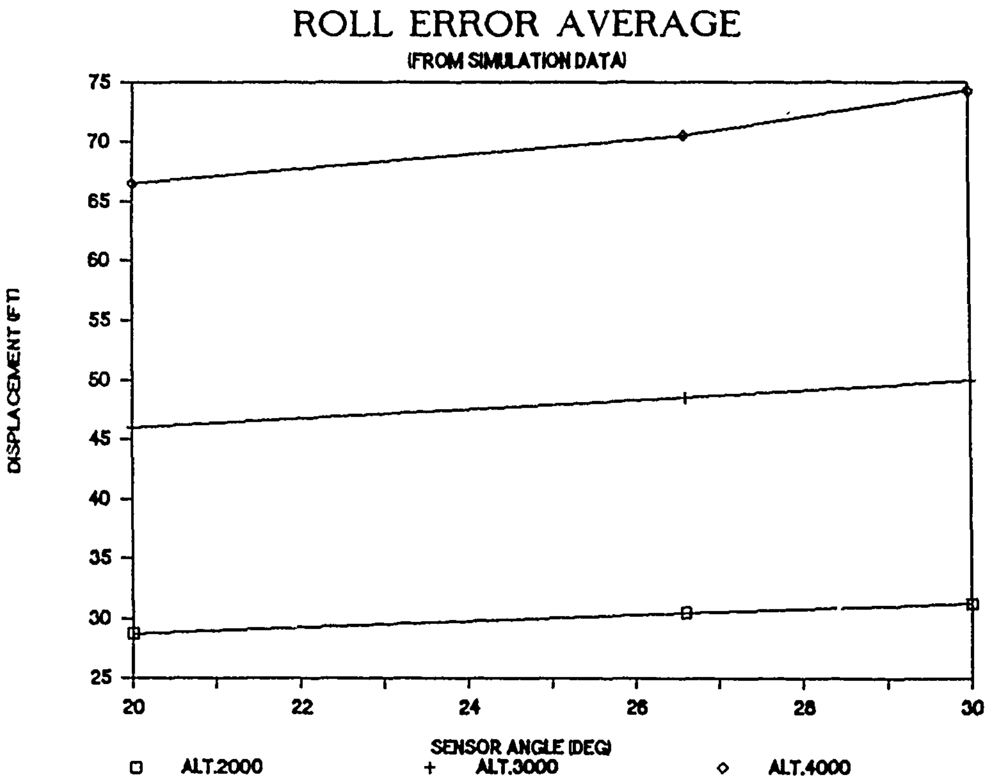

FIG 3.

Roll error simulation data average is plotted on the ordinate. The abscissa is the sensor inclination angle.

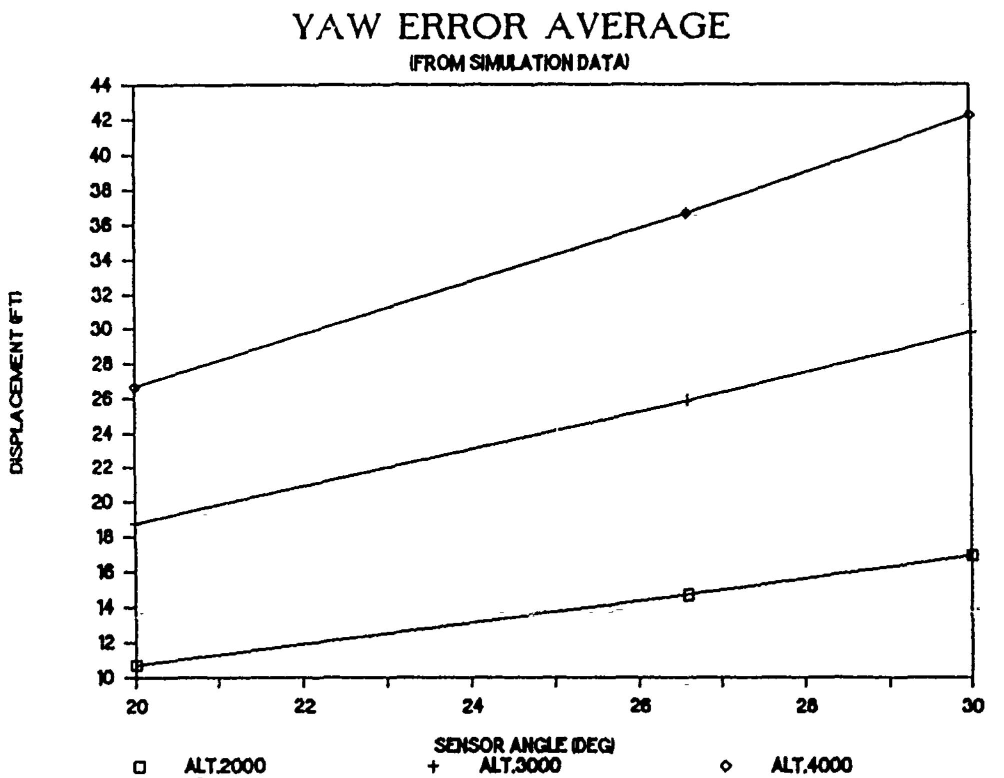

FIG 4.

Yaw error data average versus sensor inclination angle.

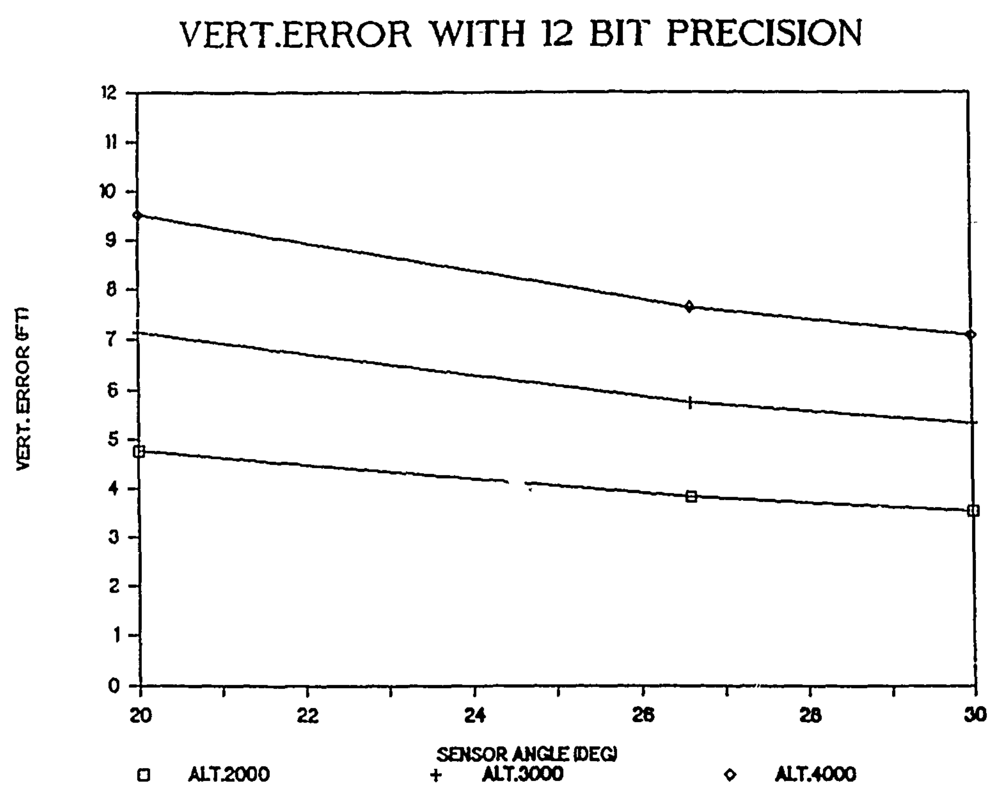

FIG 5.
The above plots exhibit the height error remaining if the imagery could be corrected to the indicated bit precision. The plots are a function of sensor angle and altitude.

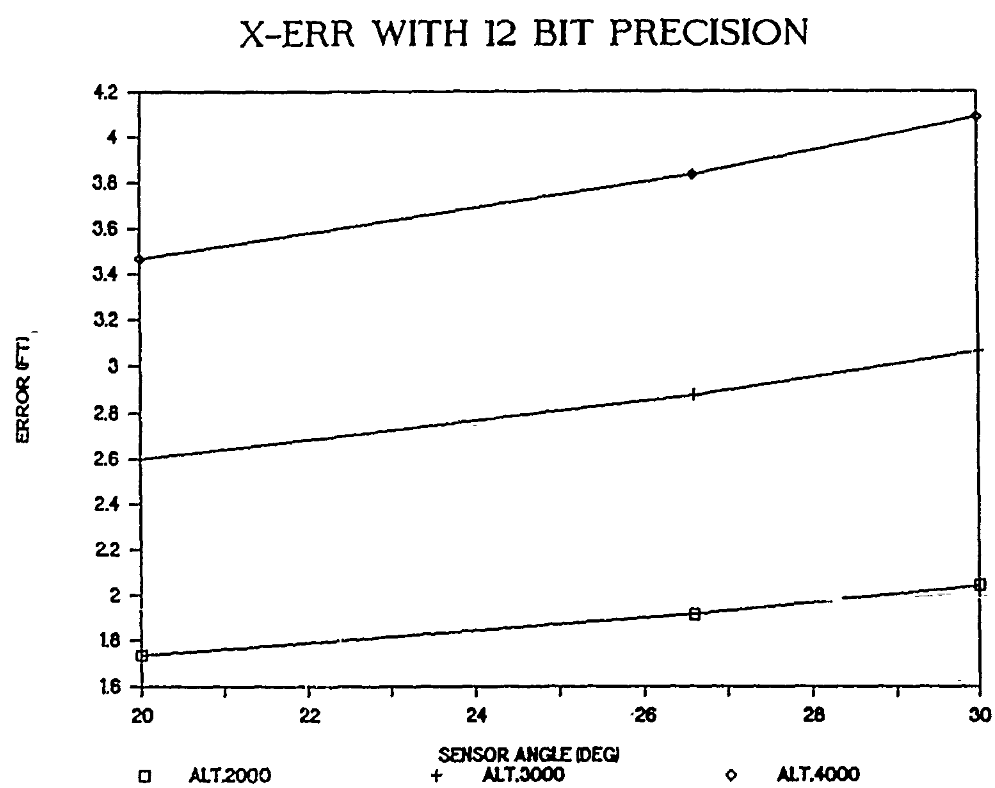

FIG 6.
X-err with 12 bit precision.

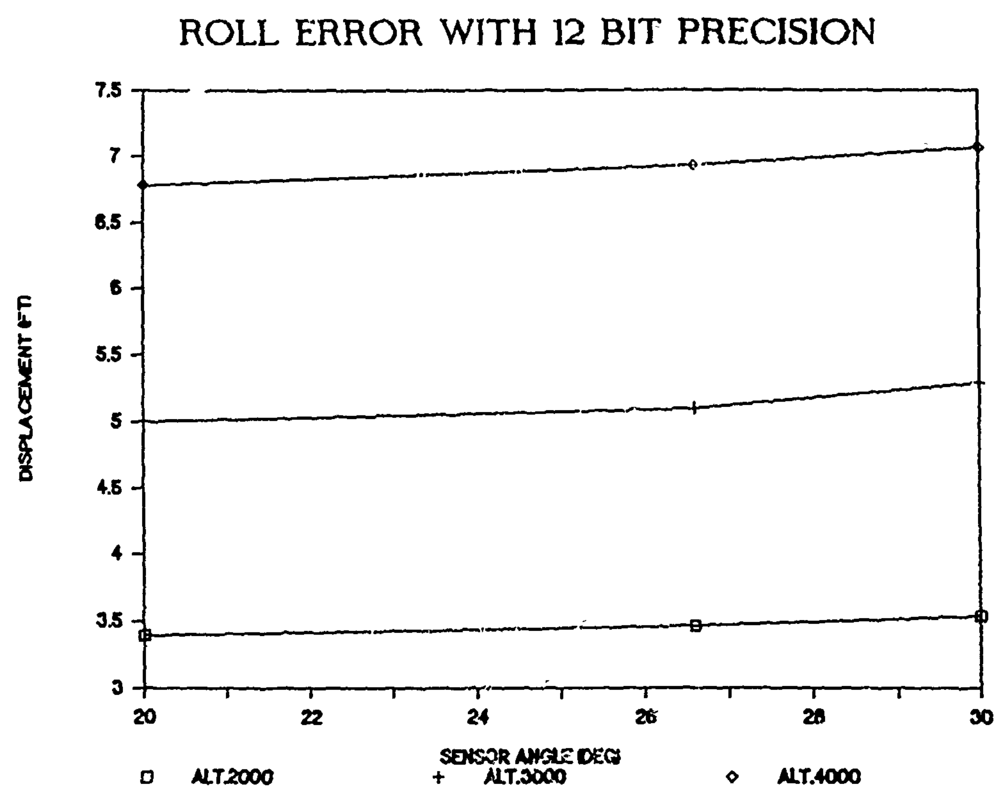

FIG 7.
Roll error with 12 bit precision.

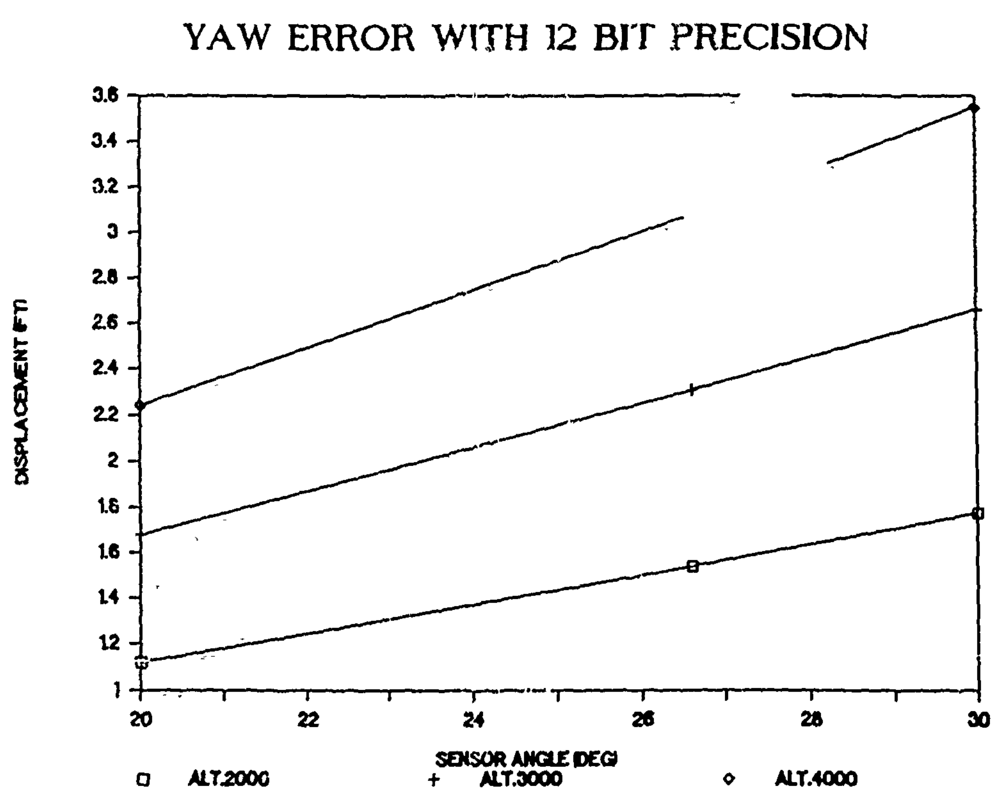

FIG 8.
Yaw error with 12 bit precision.